

RAYTHEON

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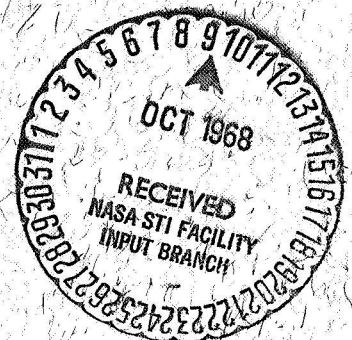
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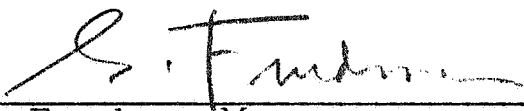
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## ABSTRACT

During the fifth interim period of thermionic-cathode evaluation, diodes using pore-dispenser cathodes have completed at least 6700 hours of life burning and are operating satisfactorily at cathode temperatures of 950°C to 1100°C and at current densities of 0.2A/cm<sup>2</sup> to 1.6A/cm<sup>2</sup>.

Diodes using standard barium-strontium-oxide cathodes have completed life burning times varying from 3400 to 5500 hours. The diodes are showing cathode emission slump at current densities above 0.15 A/cm<sup>2</sup> and cathode temperatures of 825°C and 850°C under T<sub>3</sub> and T<sub>4</sub> operating conditions.

A new cathode evaluation program using three new nickel cathode alloys with oxide cathodes and coated-particle cathodes in the test diode is outlined.

## TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1. 0	Introduction	1
2. 0	Life Burning and Testing of Pore-Dispenser Cathode	1
3. 0	Life Burning and Testing of Oxide-Coated Cathodes	7
4. 0	Conclusions and Recommendations	12

## LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
1	Life - Test Results Pore - Dispenser Cathodes	3
2	Life - Test Results Pore - Dispenser Cathodes	4
3	Life - Test Results Pore - Dispenser Cathodes	5
4	Life - Test Results Pore - Dispenser Cathodes	6
5	Life - Test Results Oxide - Coated Cathodes	8
6	Life - Test Results Oxide - Coated Cathodes	9
7	Life - Test Results Oxide - Coated Cathodes	10
8	Life - Test Results Oxide - Coated Cathodes	11

## 1.0 INTRODUCTION

The Material and Techniques Group of Raytheon's Microwave and Power Tube Operation is performing a study of the life capabilities of three different types of thermionic-emitters for the Jet Propulsion Laboratory, California Institute of Technology.

The life capabilities of the following electron-tube cathode types are to be evaluated for a period of two years of life testing.

- a. Pore-dispenser cathode
- b. Coated-particle cathode
- c. Standard oxide cathode

During this fifth interim period of the contract, the thirty-one diodes using pore-dispenser cathodes and oxide cathodes were continued on life burning. The results are reported in Sections 2.0 and 3.0.

No further work was performed on coated-particle cathodes. Also, no diodes were built during this interim period.

## 2.0 LIFE BURNING AND TESTING OF PORE-DISPENSER CATHODE

The test diodes with pore-dispenser cathodes under  $T_1$ ,  $T_2$ , and  $T_3$  conditions, have completed 6848 hours of life burning as of the end of this fifth interim period of study.

The test diodes under  $T_4$  conditions have completed 6729 hours of life burning. The life-test results are shown in Table 1 ( $T_1$ ), 2 ( $T_2$ ), 3 ( $T_3$ ) and 4( $T_4$ ).

At each interval of life burning, as noted in the tables, the cathode current is recorded for each diode at its pre-determined cathode temperature and constant anode voltage. The current is also read at  $\pm 20\%$  of the specified anode voltage of the test diode.

The diodes are removed from the life-test racks and are read for dip temperature according to the procedure previously described in the first interim report, Thermionic Cathode Evaluation Study, January 1 - June 30, 1967.

The cathode current is also determined for 95% of the operating temperature from the dip-temperature curve trace.

Neither the diodes operating under  $T_1$  conditions (950°C cathode temperature and 0.2 and 0.4 A/cm<sup>2</sup> anode current) nor the diodes operating under  $T_2$  conditions (cathode temperature 925°C and 0.4 A/cm<sup>2</sup>) have shown any significant changes in operating currents up to this point in life burning (6848 hours). The dip temperature has increased from 26°C to 41°C for the two diodes.

The diodes operating under  $T_2$  conditions, (985°C and 0.8 A/cm<sup>2</sup> anode current) have shown a 20% decrease in anode current at this point in life burning.

The diodes operating under  $T_3$  conditions (1035°C cathode temperature and 0.6 and 1.2 A/cm<sup>2</sup>) have not shown any significant changes in operating characteristics up to this point in life burning (6848 hours).

One diode under  $T_4$  conditions (1100°C cathode temperature and 0.8 A/cm<sup>2</sup> anode current) has shown a slump of 15% in cathode current.

In summary, it can be said that the pore-dispenser cathodes have operated satisfactorily up to 6700 hours of life burning from 950°C to 1100°C with the cathode current varying from 0.2 A/cm<sup>2</sup> to 1.6 A/cm<sup>2</sup>.

TABLE 1  
Life - Test Results  
Pore - Dispenser Cathodes

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T °C	Ip @ 95%T
T <sub>1</sub> -950°C 0.2 A/cm <sup>2</sup>	M1  Ef = 9.0V	0	10.0	39V	8.4 - 12.0	880	8.70
		2688	8.9		8.9 - 13.2	891	8.00
		4796	9.0		9.0 - 13.2	886	8.69
		5453	11.1		9.0 - 13.3	870	8.55
		6192	11.1		9.0 - 13.3	892	8.50
		6848	11.0		8.9 - 13.0	887	8.75
	M4  Ef = 9.0V	0	10.0	26V	8.3 - 12.5	888	8.81
		2688	10.0		8.4 - 12.2	906	8.25
		4796	10.0		8.2 - 11.9	904	7.98
		5453	9.9		8.2 - 11.9	910	7.90
		6192	9.9		8.1 - 11.8	910	8.00
		6848	9.8		8.1 - 11.8	887	8.41
T <sub>1</sub> - 950°C 0.4A/cm <sup>2</sup>	M2  Ef = 9.0V	0	20.0	49V	15.1 - 27.3	916	19.3
		2688	21.2		16.1 - 25.9	896	17.5
		4796	21.0		16.2 - 25.4	896	17.8
		5453	21.0		16.1 - 25.2	870	17.6
		6192	20.9		16.0 - 25.0	910	17.1
		6848	20.0		15.6 - 23.2	882	17.8
	M3  Ef = 9.0V	0	20.0	35V	16.5 - 27.0	897	15.0
		2688	20.7		16.2 - 25.2	907	16.6
		4796	21.0		16.5 - 25.8	872	18.5
		5453	21.0		16.4 - 25.2	877	17.6
		6192	21.0		16.4 - 25.2	904	17.1
		6848	20.8		16.2 - 24.1	901	16.3



TABLE 2  
Life - Test Results  
Pore - Dispenser Cathodes

Test	Diode	Hours	$I_p$ (ma)	Volts	$I_p \pm 20\% V$	Dip $T^{\circ}C$	$I_p$ @ 95%T
$T_2 - 985^{\circ}C$ $0.4 A/cm^2$	M7  Ef = 9.0V	0	20.0	34.5V	16.8 - 27.5	899	19.3
		2688	20.0		15.8 - 24.4	957	16.6
		4796	23.3		18.5 - 29.6	954	16.8
		5453	23.5		18.7 - 29.9	947	18.6
		6192	23.5		18.8 - 30.0	954	16.9
		6848	22.2		17.9 - 28.0	940	17.5
	M9  Ef = 9.0V	0	20.0	40V	14.6 - 28.5	910	18.8
		2688	22.5		15.9 - 29.1	938	17.7
		4796	22.4		16.0 - 29.2	938	17.8
		5453	22.5		15.9 - 29.1	938	17.7
		6192	22.4		16.0 - 29.2	938	17.8
		6848	22.0		15.8 - 28.4	936	17.9
$T_2 - 985^{\circ}C$ $0.8 A/cm^2$	M11  Ef = 9.0V	0	40.0	65V	32.0 - 49.5	964	28.0
		2688	27.5		30.8 - 45.8	979	30.3
		4796	37.0		30.2 - 43.6	985	31.3
		5453	36.7		30.0 - 43.5	974	30.8
		6192	36.0		29.5 - 42.4	976	33.8
		6848	35.0		29.0 - 39.1	975	27.5
	M12  Ef = 9.0V	0	40.0	54V	31.0 - 50.0	913	38.0
		2688	37.0		29.2 - 45.0	957	32.0
		4796	35.0		27.9 - 42.4	985	31.8
		5453	34.0		27.0 - 40.8	962	30.8
		6192	35.0		27.9 - 41.8	943	34.5
		6848	33.5		26.9 - 40.0	971	29.3

TABLE 3  
LIFE - TEST RESULTS  
PORE-DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T°C	Ip @ 95%T
T <sub>3</sub> - 1035°C  0.6 A/cm <sup>2</sup>	M13	0	30.0	45V	22.5 - 38.5	965	29.2
		2688	30.0		23.9 - 39.8	961	26.4
	Ef=11.0V	4796	31.0		24.3 - 40.5	967	27.4
		5453	31.5		23.9 - 40.0	957	28.2
		6192	31.4		23.8 - 39.6	970	28.0
		6848	31.7		23.9 - 39.8	980	26.5
	M18	0	30.0	48.5	21.5 - 38.0	949	29.2
		2688	30.0		23.0 - 37.8	1003	25.6
	Ef=11.0V	4796	31.7		24.5 - 40.0	1005	24.2
		5453	31.0		23.5 - 38.0	999	25.2
		6192	30.9		24.8 - 40.0	999	24.0
		6848	31.2		24.3 - 39.2	1005	25.5
T <sub>3</sub> - 1035°C  1.2 A/cm <sup>2</sup>	M17	0	60.0	90V	45.0 - 78.5	993	55.5
		2688	61.2		47.8 - 77.4	1020	51.6
	Ef=11.0V	4796	62.9		49.2 - 76.8	1017	52.0
		5453	63.3		49.6 - 76.8	1027	52.0
		6192	63.2		49.7 - 77.4	1027	51.6
		6848	63.0		49.4 - 76.8	1023	52.0
	M14	0	60.0	98V	44.5 - 69.0	995	56.0
		2688	54.9		41.2 - 70.2	977	55.2
	Ef=11.0V	4796	61.7		46.4 - 78.0	974	55.4
		5453	56.9		42.9 - 71.2	993	54.4
		6192	56.0		42.0 - 67.0	980	55.2
		6848	55.2		41.8 - 70.3	988	55.0

TABLE 4  
LIFE - TEST RESULTS  
PORE - DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T <sup>o</sup> C	Ip @ 95%T
T <sub>4</sub> -1100 <sup>o</sup> C  0.8A/cm <sup>2</sup>	M21  Ef=11.0V	0	40.0	57V	23.0 - 52.0	957	37.6
		2521	46.4		28.8 - 59.5	1055	34.6
		4729	48.0		29.4 - 60.8	1032	36.0
		5386	48.4		30.0 - 61.5	1032	33.0
		6079	49.2		34.7 - 63.0	1029	32.5
		6729	50.0		30.9 - 63.0	1049	33.0
	M23  Ef=11.0V	0	40.0	73K	24.0 - 51.0	997	38.0
		2521	37.2		23.9 - 45.8	1079	31.0
		4729	34.8		22.9 - 42.3	1089	34.9
		5386	38.9		25.9 - 44.4	1089	27.0
		6079	36.8		25.0 - 43.4	1091	28.1
		6729	34.0		23.9 - 40.8	1100	31.0
T <sub>4</sub> -1100 <sup>o</sup> C  1.6A/cm <sup>2</sup>	M19  Ef=11.0V	0	80.0	110V	61.0 - 94.0	1049	77.0
		576	80.2		61.3 -100.0	1039	75.0
		1297	80.0		62.4 - 98.0	1053	65.0
		2009	79.2		62.8 - 98.5	1066	65.0
		2521	84.5		67.0 -104.0	1075	61.0
		2713	HEATER BURNOUT				
	M22  Ef=11.0V	0	80.0	106V	59.0 -100.0	1039	73.0
		2521	86.5		71.7 -110.0	1051	66.0
		4729	88.3		74.4 -110.0	1100	65.0
		5386	87.9		74.4 -110.0	1100	61.5
		6079	88.1		74.9 -110.0	1100	68.1
		6729	88.0		74.9 -110.0	1100	65.0

### 3.0 LIFE BURNING AND TESTING OF OXIDE-COATED CATHODES

The test diodes with oxide-coated cathodes under  $T_1$  and  $T_2$  conditions have completed 3390 hours of life burning at the end of this fifth interim period.

The test diodes under  $T_3$  and  $T_4$  conditions have completed 5520 hours of life burning.

The life test results are summarized in Tables 5 ( $T_1$ ), 6 ( $T_2$ ), 7 ( $T_3$ ), and 8 ( $T_4$ ).

The diodes with oxide cathodes under  $T_1$  conditions (cathode temperature  $800^\circ\text{C}$ , anode current 0.075 and  $0.15\text{ A/cm}^2$ ) and under  $T_2$  conditions ( $825^\circ\text{C}$  cathode temperature and 0.15 and  $0.30\text{ A/cm}^2$ ) have not shown any significant changes in anode current up to 3390 hours. The dip temperature for the diodes under  $T_2$  conditions have shown a rise to  $825^\circ\text{C}$  (operating temperature).

Three of the diodes under  $T_3$  conditions have shown a slump of 30% to 50% in anode current at this point in life burning. The dip temperature is also at  $825^\circ\text{C}$  (operating temperature).

Three diodes under  $T_4$  conditions have shown a slump of 26% to 46% in anode current up to 3520 hours of life burning. The dip temperature is up to  $850^\circ\text{C}$  (operating temperature).

In general; all cathodes operating above  $0.15\text{ A/cm}^2$  are showing varying conditions of slumping cathode emission, though no diodes have shown complete emission failure.

TABLE 5  
LIFE - TEST RESULTS  
OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T °C	Ip @ 95%T
T <sub>1</sub> -800°C 0.075A/cm <sup>2</sup>	O-32  Ef=8.0V	0	6.0	19.5V	4.7 - 7.9	722	4.13
		694	5.8		4.5 - 7.0	659	5.60
		1371	6.0		4.9 - 7.4	666	5.14
		2009	6.0		4.8 - 7.0	718	5.03
		2748	5.8		4.8 - 6.9	711	5.00
		3390	5.6		4.6 - 6.7	718	5.03
	O-35  Ef=8.0V	0	8.0	18.5V	7.1 - 9.7	750	4.13
		694	7.4		7.2 - 8.5	748	5.55
		1371	7.8		7.2 - 8.9	740	5.14
		2009	7.8		7.1 - 8.9	771	4.88
		2748	7.9		7.5 - 9.0	776	4.95
		3390	7.9		7.5 - 9.0	776	4.88
T <sub>1</sub> -800°C 0.15A/cm <sup>2</sup>	O-39  Ef=8.0V	0	12.0	36.0V  8.9	9.0 - 15.1	655	10.9
		694	11.1		8.3 - 13.8	651	10.9
		1371	11.8		8.9 - 14.3	680	10.5
		2009	11.8		8.9 - 14.1	722	10.4
		2748	11.9		8.9 - 14.2	695	10.5
		3390	11.9		8.9 - 14.2	683	10.5
	O-40  Ef=8.0V	0	12.0	29.0V	9.6 - 14.7	769	9.3
		694	11.6		9.3 - 13.7	660	10.4
		1371	12.0		9.9 - 14.1	703	10.1
		2009	11.6		9.5 - 13.7	741	9.9
		2748	11.0		9.0 - 13.5	732	10.0
		3390	10.9		9.0 - 12.9	728	10.1

TABLE 6  
LIFE - TEST RESULTS  
OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T °C	Ip @ 95%T
T <sub>2</sub> -825°C  0.15A/cm <sup>2</sup>	O-38  Ef=8.0V	0	12.0	29V	9.3 - 15.2	741	11.0
		694	10.0		8.0 - 12.1	785	10.9
		1371	11.0		8.9 - 13.0	804	10.2
		2009	10.5		8.3 - 12.0	825	9.4
		2784	10.3		8.2 - 12.4	825	9.4
		3390	10.1		8.2 - 12.4	825	9.1
	O-41  Ef=8.0V	0	12.0	34V	9.1 - 14.7	727	10.8
		694	11.1		8.6 - 13.6	740	10.8
		1371	12.0		9.3 - 14.9	758	10.8
		2009	11.9		8.9 - 14.2	783	10.7
		2784	11.4		8.8 - 14.0	796	10.5
		3390	11.0		8.4 - 13.3	825	9.8
T <sub>2</sub> -825°C  0.30A/cm <sup>2</sup>	O-33  Ef=8.0V	0	24.0	45.0V	19.0 - 30.4	787	21.0
		694	19.4		15.8 - 23.6	825	17.3
		1371	20.9		16.2 - 25.4	825	20.8
		2009	20.9		16.0 - 25.4	825	19.5
		2784	21.8		16.8 - 26.9	825	20.9
		3390	21.3		16.4 - 26.3	825	19.5
	O-37  Ef=8.0V	0	24.0	56.0V	19.1 - 30.7	735	22.6
		694	19.6		15.7 - 22.8	788	21.7
		1371	21.0		17.0 - 24.7	825	18.0
		2009	20.9		16.8 - 24.6	825	20.1
		2784	20.5		16.9 - 24.0	825	20.9
		3390	20.4		16.9 - 24.0	825	20.3

TABLE 7  
LIFE - TEST RESULTS  
OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T°C	Ip @ 95%T
T <sub>3</sub> -825°C  0.225A/cm <sup>2</sup>	O-11  Ef=8.0V	0	18.0	31V	14.0 - 22.2	779	16.4
		2038	12.2		10.0 - 14.2	825	11.3
		3439	11.0		9.0 - 12.4	825	11.6
		4077	10.7		8.7 - 12.0	825	11.7
		4870	10.0		8.3 - 11.4	825	12.1
		5520	10.0		8.3 - 11.8	825	15.7
	O-15  Ef=8.0V	0	18.0	28V	13.9 - 23.5	769	16.6
		2038	12.2		12.0 - 18.7	825	11.3
		3439	14.2		11.3 - 18.0	825	13.5
		4077	14.0		11.2 - 17.7	825	12.4
		4870	12.3		9.2 - 16.0	825	13.6
		5520	12.8		11.0 - 17.2	825	13.2
T <sub>3</sub> -825°C  0.45A/cm <sup>2</sup>	O-7  Ef=8.0V	0	36.0	34V	28.0 - 45.5	783	33.5
		2038	24.9		21.0 - 28.0	825	29.0
		3439	20.0		17.0 - 22.4	825	32.8
		4077	17.7		15.1 - 20.8	825	24.3
		4870	17.8		14.9 - 20.0	825	16.9
		5520	17.0		14.3 - 20.0	825	30.2
	O-14  Ef=8.0V	0	36.0	67V	28.0 - 44.5	768	31.7
		2038	35.0		27.0 - 46.9	788	31.2
		3439	35.4		27.0 - 46.2	825	29.3
		4077	35.2		27.0 - 48.0	825	24.3
		4870	34.0		26.4 - 47.9	825	31.5
		5520	33.8		26.4 - 47.4	825	30.3

TABLE 8  
LIFE - TEST RESULTS  
OXIDE - COATED CATHODE

Test	Diode	Hours	Ip (ma)	Volts	Ip $\pm$ 20% V	Dip T <sup>o</sup> C	Ip @ 95%T
T <sub>4</sub> - 850 <sup>o</sup> C  0.3 A/cm <sup>2</sup>	O-21	0	24.0	39V	18.2 - 29.0	774	21.6
		2038	16.0		13.0 - 23.5	850	19.8
	Ef=8.0V	3439	15.0		12.2 - 19.8	850	18.3
		4077	15.0		12.1 - 18.6	850	18.2
		4870	15.0		12.2 - 18.1	850	16.5
		5520	15.8		12.9 - 18.4	850	17.3
	O-22	0	24.0	46V	19.7 - 28.0	775	18.2
		2038	17.0		13.9 - 32.8	850	15.0
	Ef=8.0V	3439	15.8		13.1 - 21.2	850	19.3
		4077	14.9		12.4 - 19.0	850	14.7
		4870	13.2		11.1 - 20.4	850	15.9
		5520	13.0		11.0 - 15.0	850	14.3
T <sub>4</sub> - 850 <sup>o</sup> C  0.6 A/cm <sup>2</sup>	O-19	0	48.0	57.5V	35.0 - 59.3	796	42.0
		2038	38.8		30.0 - 57.0	841	37.2
	Ef=8.0V	3439	41.9		31.4 - 64.5	850	36.0
		4077	46.7		33.9 - 63.9	850	39.2
		4870	44.8		32.0 - 62.1	850	37.2
		5520	42.4		32.2 - 60.8	850	42.0
	O-20	0	48.0	70V	36.8 - 60.0	769	42.6
		2038	44.9		34.0 - 59.4	831	34.2
	Ef=8.0V	3439	41.4		32.0 - 55.3	850	37.5
		4077	40.9		31.4 - 53.4	850	37.8
		4870	38.9		30.4 - 50.9	850	37.2
		5520	36.7		29.0 - 45.4	850	39.6



#### 4.0 CONCLUSIONS AND RECOMMENDATIONS

The Raytheon Materials and Techniques Group, in conducting a study of the life capabilities of the pore-dispenser cathode and oxide-coated cathodes, draws the following conclusions from twelve months of life burning under the specified conditions noted in Tables 1 through 8:

- a. The pore-dispenser cathode is suitable for dc operation for at least 6700 hours at current ranges of  $0.2 \text{ A/cm}^2$  to  $1.6 \text{ A/cm}^2$  and temperatures ranging from  $950^\circ\text{C}$  to  $1100^\circ\text{C}$ .
- b. The standard barium-strontium-oxide cathodes are showing erratic emission slump at current densities higher than  $0.15 \text{ A/cm}^2$  during the life-burning cycle.

In reference to the recommendations made in the last interim report concerning the use of more active nickel cathodes other than 0.1% Zr-Ni to improve the performance of the oxide cathode under higher current densities than  $0.15 \text{ A/cm}^2$ , the following program is being finalized for testing of oxide-coated cathodes.

- a. Build and test the following diodes (all currents in  $\text{mA/cm}^2$ ):
 

1.	Oxide cathode using 220 nickel alloy	$T_2$	1 unit at 150 ma, 1 unit at 300 ma
		$T_3$	1 unit at 225 ma, 1 unit at 450 ma
2.	Oxide cathode using A-33 nickel alloy	$T_2$	1 unit at 150 ma, 1 unit at 300 ma
		$T_3$	1 unit at 225 ma, 1 unit at 450 ma
3.	Oxide cathode using Ni Pure/ nickel alloy	$T_2$	1 unit at 150 ma, 1 unit at 300 ma
		$T_3$	1 unit at 225 ma, 1 unit at 450 ma
4.	Coated-particle cathode using A-33 nickel alloy	$T_2$	1 unit at 275 ma, 1 unit at 550 ma
		$T_3$	1 unit at 415 ma, 1 unit at 830 ma
5.	Coated-particle cathode using Ni Pure nickel alloy	$T_2$	1 unit at 275 ma, 1 unit at 550 ma
		$T_3$	1 unit at 415 ma, 1 unit at 830 ma